Lab 4. Time-Varying Fields

Name: ________________________

Section: ________________________

Task 7. The Blown Transformer

You've got a new and better position in the R&D department of a company producing digital electronic devices. One day, while you are working on a project with approaching deadline, the 5-V power supply in the lab burns out. You check the unit and find out that the rectifier and the stabilizer are ok, but the transformer has burned out. You order a new power supply but it will arrive the next day and you cannot afford to loose a whole day. You know that designing and building the transformer shouldn't take more than an hour. So, you decide to do it in order to save the day. To get 5 volts from the supply, the output of the transformer must be at a somewhat higher voltage since the rectifier and the stabilizer will lower it further.

So, you need to construct a transformer that will convert the 120 V_{rms} from the outlet into 8 V_{rms}. The transformer must provide 40 W of power.

In the lab, there is a ferromagnetic material in the form of a long cylindrical rod. You decide to use this material to make the transformer in the form of two coaxial coils (two solenoids sharing the same core).

First, you need to figure out wires of what diameters are to be used in the primary and the secondary coils so that get the necessary wires from the stock room. You are sure that the current density in the wires should not exceed 2.5 A/mm^2. You decide to assume that the transformer is ideal and to counteract this assumption by incorporating a safety factor of 1.5 in your calculations to make sure the maximum permissible current density won't be exceeded under any circumstances.

In order to choose wires of proper diameters, you first compute the current through the primary and the secondary coils. Since the transformer is assumed to be ideal, the powers associated with the two coils are equal, $P_1 = V_1 I_1 = V_2 I_2$, and the currents through the primary and the secondary coils are $I_1 = \dfrac{P}{V_1} = \dfrac{1}{3}\,\text{A}$ and $I_2 = \dfrac{P}{V_2} = 5\,\text{A}$, respectively. Then, using a safety factor of 1.5,

$$1.5 I_1 = J_{\max}\pi\left(\frac{d_1}{2}\right)^2 \qquad \Rightarrow \qquad d_1 = 2\sqrt{\frac{1.5 I_1}{J_{\max}\pi}} = 2\sqrt{\frac{1.5\times 1/3}{2.5\times 10^6\pi}} = 0.5\,\text{mm}$$

$$1.5 I_2 = J_{\max}\pi\left(\frac{d_2}{2}\right)^2 \qquad \Rightarrow \qquad d_2 = 2\sqrt{\frac{1.5 I_2}{J_{\max}\pi}} = 2\sqrt{\frac{1.5\times 5}{2.5\times 10^6\pi}} = 1.95\,\text{mm} \approx 2\,\text{mm}$$

After you've got the proper wires from the stock room, you look up the specifications of the ferromagnetic rod and find out that its permeability is $\mu_r = 400$ and its cross-sectional area is 0.9 cm^2.

To shorten the piece of ferromagnetic material needed for the core, you've decided that the **secondary coil** will consist of **3 layers of windings**.

You figure out how long piece of the ferromagnetic rod you need to cut and how many turns of wire you need to wind for the primary and the secondary coils.

Finally, you are ready to actually build the transformer. First, you wind the secondary coil and put a couple of layers of insulating foil on top. Then you wind the primary coil, cover it with layers of insulating foil and eventually, you soak the transformer in shellac for added insulation and sturdiness.

To complete the assignment:

1. Assume that the ferromagnetic core is long enough to permit the use of the expressions for infinitely long solenoid.
2. Neglect the thickness of the wire layers when computing the magnetic field.
3. Neglect the thickness of the wires' insulation.
4. Fill in the Task Report Questionnaire.
5. Hand in your work at the next lab period.
6. **Show all your work, to receive full credit.**

Task 7. The Blown Transformer

Questionnaire

Give brief but accurate and thorough explanation if necessary. Provide math expressions where needed to show how you've obtained the particular result.

1. Which one of the coils will have a larger number of turns?

2. How does the effective value of the voltage, V_{rms}, across a coil depend on the number of turns, N, in the coil? Provide the general expression.

3. Provide the general expression about the number of turns, N, of wire of certain diameter, d, that would fit in k layers around a ferromagnetic core of length l.

4. Using your answers to the previous two questions, write an expression about the number of turns in the coil, N, that does not depend on the length of the core.

5. Use your answer to the previous question to figure out the number of turns that are needed in the secondary coil?

6. How many turns of wire are needed in the primary coil?

7. Compute the length of the ferromagnetic core.

8. How many layers of wire make up the **primary** coil?

9. What is the overall length of wire needed for the **secondary** coil? Take into account wire's thickness.

Task 8. The Navy Project

You have successfully obtained a Bachelor's degree in EE and currently you are enrolled in the graduate program of the EE Department. You want to taste a real research, so you've chosen the thesis option for your Master's degree. You work under the supervision of a faculty member who has just secured a contract with the Navy. It is about RF communications with submarines. The Navy has provided the following data: The shore base station can emit within the frequency range 1KHz to 1MHz with a signal strength, such that just below the water surface it is 10 mV/m. The submarine receiver can tolerate attenuation of 60 dB with respect to the wave's amplitude just below the water surface.

Your boss has asked you to obtain a log-log curve showing the frequency dependence of the maximum depth, at which a submarine can still receive messages from the shore base station.

You quickly review the decibel scale for amplitude and power ratios and realize that the **sensitivity of the receiver**, $E_{\min}$, is 10 μV/m:

$$-60 = 20\log_{10}\left(\frac{E_{\min}}{E_0}\right) = 20\log_{10}\left(\frac{E_{\min}}{0.01}\right)$$

$$E_{\min} = 0.01\times 10^{-3} = 10^{-5} = 10\,\mu\text{V/m}$$

You look up the properties of sea water at radio frequencies: conductivity of 4 S/m and relative permittivity of 81. Then, you write a short MATLAB code that generates the plot and you analyze the result.

Now, your professor is happy and is going to put you on a research fellowship starting next semester!

To complete the assignment:

1. Review the lecture notes and the book on EM wave propagation in lossy media.
2. Answer the first four questions in the Task Report Questionnaire.
3. Write a MATLAB code that plots a log-log graph of the maximum depth versus frequency. ***Note:*** In MATLAB command window, type *help loglog* to learn more about this function. The axes of the graph must be properly labeled.
4. Print out your MATLAB code and the graph.
5. Answer the rest of the questions in the Task Report Questionnaire.
6. Hand in your work at the next lab period.
7. **Show all your work, to receive full credit.**

Task 8. The Navy Project

Questionnaire

Give brief but accurate and thorough explanation if necessary. Provide math expressions where needed to show how you've obtained the particular result.

1. Provide the general expression which you would use to compute the loss tangent of sea water.

2. Is the sea water a good conductor, a low-loss dielectric, or neither, within the base station's operating frequency range? Prove your point by providing values.

3. What is the penetration depth at 1 KHz? Give the math expression and the value.

4. Provide an expression about the maximum depth, at which the submarine would receive the signal reliably, in terms of the penetration depth.

5. How much time does it take for the signal to travel from the water surface to the submarine when it is submerged at 50 m if the signal frequency is 1 KHz? Show your work in computing the value.

6. From the plot, when the submarine is submerged to 10 meters, what is the highest frequency, at which it can receive messages from the shore?

7. From the plot, at the highest available frequency (1 MHz), what is the maximum depth at which the submarine can be and still receive messages from the shore?

8. From the plot, when the submarine is submerged to 100 meters, at what frequency must the shore base station send the signals?

9. From the plot, if the submarine is at a depth of 10 meters and the base station transmits at 10 KHz, will the submarine receive the message?